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CERTAIN INVESTIGATIONS ON ATMOSPHERIC TURBULENCE STRENGTH (C_n^2) PREDICTION MODELS FOR FSO APPLICATIONS

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ABSTRACT: Free-space optical (FSO) communication has become more interesting alternative to radio frequency communication over the last two decades because of its performance. Generally FSO system requires free line of sight between the transmitter and receiver. Compared to glass, a light travel through the air is faster. When the optical wave is propagating through the turbulence transmission medium, the performance of the Free Space Optical (FSO) communication system is strongly affected by the Atmospheric parameters. Various factors are affecting the performance of the communication channel in free space optical communication system. Developing model to get an accurate prediction of turbulence strength (Cn2) becomes significant to understand the behavior of channel in different seasons. This paper deals with the survey of channel model such as Pamela, Hufnagel valley, Gamma-Gamma models.
Keywords: Free Space Optical (FSO), Line of Sight (Los).

I. INTRODUCTION

FSO communication is infrared wireless laser-based point-to-point communication in which each point has a direct line-of-sight (LoS) between them. The FSO communication has been demonstrated at multi- Gbps data rates for few kilometer distances. FSO technology uses unlicensed optical wavelengths, which offers the high broadband communication capacity. The major impact on the quality of a laser beam propagating through the atmosphere over long distances is the atmospheric turbulences [1]. The received signal exhibits random intensity fluctuations in the presence of atmospheric turbulence. The greatest challenge of FSO is the performance evaluation under considering the effects of the atmospheric turbulences. Free space optical communications, is less expensive and high bandwidth access technique, which is receiving increasing attention with recent commercial application. Atmospheric turbulence is the major impact over FSO links [2], which severely degrading the link performance. In this paper the detailed survey of channel models are presented.

II. EXPERIMENTAL SETUP

FSO communication technology is relatively simple. Based on the connectivity between FSO units, each consisting of an optical transceiver with a laser transmitter and a laser receiver to provide bi-directional capability. Each FSO unit uses a high-power optical source (i.e. laser or LED), added with a lens, which transmits light through the atmosphere to another lens receiving the information. The receiver lens connects to a high-sensitivity receiver through optical fiber. The major subsystems in an FSO communication system are illustrated in Figure 1.A data input produced by source is transmitted to a remote destination. The source output is modulated onto an optical carrier. Typically laser is then transmitted as an optical field through the atmospheric channel. Size, power and beam quality are the important aspects of the transmitter. Beam quality is used to determine the laser intensity and minimum divergence obtainable from the system [3]. The aperture size and the f-number are the important features on the receiver side. The f/-number is used to determine the amount of the collected light and the detector field-of-view (FOV). The optical field is collected and detected generally in the presence of noise interference, signal distortion, and background radiation at the receiver side. The source data is modulated in three different ways: amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), each of which can be theoretically implemented at any frequency.

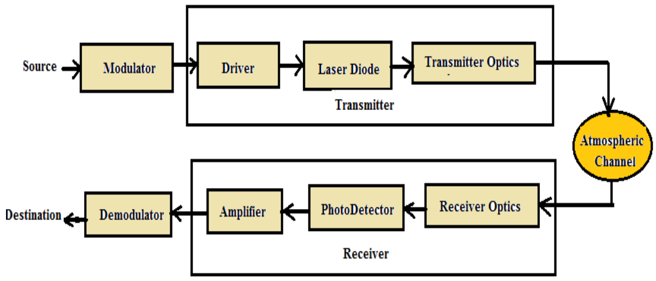

Figure1. BLOCK DIAGRAM OF FSO

III. CHALLENGES OF FSO

Free Space Optical communication (FSO) based wireless systems are not without challenges. The major limitation of free space optical communications emerges from the environmental factors through which it propagates. However relatively unaffected by rain and snow, free space optical communication systems can be severely affected by fog, beam wandering effects, scintillation and scattering effects [4].

A. Factors affecting FSO:

Many factors affect the performance of the FSO communication system. While designing the system, it is necessary to keep these factors and their effect on the system performance to achieve maximum performance.

B. Scattering: Scattering is the form of radiation such as light passing through the atmosphere which is forced to deviate from a straight line trajectory due to localized non-uniformities present in the atmosphere. Light scattering can radically affect the performance of FSO communication systems. Scattering is not related to a loss of energy due to a light absorption process rather it can be understood as a redirection or redistribution of light that can lead to a significant reduction of received light intensity at the receiver location.

C. Absorption: Atoms and molecules are naturally characterized by their refractive index. The imaginary part of the refractive index, k, is related to the absorption coefficient, α, which is given by the following equation:

$$\alpha = \frac{4\pi k}{\lambda} = \sigma_A N_A \qquad (1)$$

Where $'\lambda'$ is the wavelength of the source is, σ_a is the density and NA is the coefficient.

D. Rain: Rain has a distance reducing nature in FSOC. When compared to fog, it has less significant impact. This is because the radius of raindrops (200–2000 μm) is significantly larger than the wavelength of typical FSOC light sources [5]. Typically the rain attenuation values are moderate in nature.

E. Snow: Snowflakes are ice crystals that come in a different shapes and sizes. In general, however, snow tends are to be larger than rain. White out conditions might attenuate the beam, but scattering doesn't tend to be a big problem for FSOC systems because the size of snowflakes is larger when compared to the operating wavelength [6]. The impact of light snow to blizzard and white out conditions are falls approximately between light rains to moderate fog with link attenuation potentials of approximately 3× dB/km to 30 × dB/km.

F. Fog: Fog is the most detrimental weather phenomenon to FSOC because it is composed of small water droplets with radii about the size of near infrared wavelengths. The particle size distribution changes for different degrees of fog [6].

IV. OPTICAL TURBULENCE MODELS

Atmospheric conditions are apparently affecting the performance of FSOC system making them highly susceptible to degrading effects of pointing errors and atmospheric turbulence strength (C_n^2). The main factors which can reduce the link performance of FSOC are aerosol, scattering effects caused by rain, snow and fog. The major factor causing pointing errors is sway of high rise buildings which in turn is caused due to thermal expansion, dynamic wind loads and big earthquakes. Another most important impairment in the FSOC system performance is the C_n^2. In homogeneity in the temperature and pressure fluctuations leads to variations in the refractive index, results in C_n^2 and causes the random fluctuations of the phase and intensity of the received signal known as channel fading [7]. Intensity fluctuations caused by channel fading leads to an increase in the system's BER. The C_n^2 not only varies as a function of altitude(h), but also according to local conditions such as terrain type, geographic location, cloud cover and time of day. Several dozen turbulence profile models have been developed from experimental measurements made at a variety of locations [8]. Most are designed based on the structure of optical turbulence profile with the units of measurement for h and C_n^2 being m and $m^{-2/3}$ respectively. A number of statistical channel models have been proposed to describe weak or strong atmospheric-induced turbulence fading. In this aspect, the PAMELA, Hufnagel-valley model, Beam wandering model, Polynomial Regression models were derived and briefed.

A. PAMELA Model: The PAMELA model provides the atmospheric strength within the surface boundary layer. The latitude, longitude, date, time of day, percent cloud cover, and terrain type, as well as the single measurement of the atmospheric temperature, pressure, and wind speed at the desired height are the inputs [9]. PAMELA model was adapted from more complicated similarity based optical turbulence models which is given in equation 2, provides C_n^2 estimation within the surface boundary layers and it accepts all the above parameters of test fields as a inputs. The measured meteorological parameters are given to the model to estimate the turbulence strength.

$$C_n^2 = \left\{5.152\varphi_{hh_h}\left(\frac{1}{\varphi_m-\zeta}\right)^{0.33}\left(\frac{77.6\times10^{-6}Pr}{T^2}\right)^2 h^{-0.667}\left(\frac{-H}{C_\rho \rho u_*}\right)^2\right\} \qquad (2)$$

Where φ_{hh_h} is the temperature gradient, φ_m is wind shear estimated from the wind speed, ζ is eddy dissipation rate, H is heat flux, C_ρ is specific heat, ρ is mass density, u_* friction velocity. From equation (4), $C_n^2 \rightarrow \infty$ as Ws $\rightarrow$ 0, therefore the minimum wind speed is bounded away from zero i.e 0.27 ms^{-1}.

*B. Hufnagel-ValleyModel***:** The Hufnagel Valley model is one of the popular models for inland sites and dayti me viewing conditions [10]. It permits variations in high altitude wind speed and near ground turbulence levels. In this model atmospheric turbulence strength is assigned as a sum of three exponential decay terms corresponding to a surface boundary layer, a strong layer caused by the high altitude jet stream, and a background tropopause layer, which is given in equation 3.

$$c_n^2(h) = A\exp\left(-\frac{h}{100}\right) + 5.94\times10^{-53\left(\frac{v}{27}\right)^2 h^{10}\exp}\left(-\frac{h}{1000}\right) + 2.7\times\ 10^{-16\exp}\left(-\frac{h}{1500}\right) \qquad (3)$$

Where, A is the nominal value of C_n^2 at the ground level and v is the estimated high altitude RMS wind speed in m/s in the 5-20 km altitude range. Commonly used values are $A = 1.7\times10^{-14v}$ and $v = 21$ m/s .To illustrate the effect of changing these two parameters, two values of moderate to strong high altitude wind speeds were used to calculate the C_n^2 profiles.

C. Gamma-Gamma model: Andrews et.al introduced the modified Rytov theory and proposed gamma-gamma pdf as a useful mathematical model for atmospheric turbulence. This modified Rytov theory defines the optical field as a function of perturbations which are due to large scale and small scale atmospheric effects. For weak to strong atmospheric turbulence the Gamma-Gamma distribution is suitable [11]. This choice arises from the fact that this model can be directly related to atmospheric conditions and, thus, considered valid even up to strong turbulence. The pdf of a Gamma-Gamma distributed signal irradiance I has the following form given in equation (4),

$$p_I(I) = \frac{2(ab)^{\frac{a+b}{2}}}{\Gamma(a)\Gamma(b)} I^{\frac{a+b}{2}-1} K_{a-b}(2\sqrt{abI}) \qquad (4)$$

Where $K_v(.)$ is the modified Bessel function of the second kind of order v, $\Gamma(.)$ is the Gamma function, while the parameters a, b can be directly related to atmospheric conditions through the expressions present in equation (5) and (6),

$$a = \left[exp\left(\frac{0.49\alpha^2}{\left(1+0.18d^2+0.56\alpha^{\frac{12}{5}}\right)^{\left(\frac{7}{6}\right)}} \right) - 1 \right]^{-1} \qquad (5)$$

$$b = \left[exp\left(\frac{0.51\alpha^2\left(1+0.69\alpha^{\frac{12}{5}}\right)^{-\left(\frac{5}{6}\right)}}{\left(1+0.9d^2+0.62d^3\,\alpha^{\frac{12}{5}}\right)} \right) - 1 \right]^{-1} \qquad (6)$$

While, $= \frac{\sqrt{kD^2}}{4L}$, $k=2\pi/\lambda$, is the optical wave number, L is the length of the link, and D is the aperture diameter of the receiver .The parameter α^2 is the Rytov variance and in this case is given in equation (7)

$$\alpha^2 = 0.5C_n^2 k^{\frac{7}{6}} L^{\frac{11}{6}} \qquad (7)$$

Where C_n^2 is the atmospheric turbulence strength, which is altitude dependent and varies from $10^{-17} m^{-2/3}$ to $10^{-13} m^{-2/3}$ for weak up to strong turbulence, respectively. The following pdf for the electrical *SNR*, γ, can be obtained in equation (8),

$$P_\gamma(\gamma) = \frac{(a+b)^{\frac{a+b}{2}}}{\Gamma(a)\Gamma(b)} \frac{\gamma^{\frac{(a+b)}{4}-1}}{\Gamma^{\frac{a+b}{4}}} \; K_{a-b}\left[2\sqrt{ab}\sqrt{\frac{\gamma}{\Gamma}}\right] \qquad (8)$$

Where Γ is the average electrical *SNR* at the receiver, given by $\Gamma = \frac{(\eta E[I])^2}{N_o}$ and $E\ [.]$ is the expected value which is normalized to unity. Substituting in, the average capacity of a Gamma-Gamma modeled optical channel will then be given by equation (9),

$$< c > = \frac{B\left(\frac{ab}{\sqrt{\Gamma}}\right)^{\frac{a+b}{2}}}{\Gamma(a)\Gamma(b)\ln(2)} \times \int_0^\infty \ln(1+\gamma)\,\gamma^{\frac{a+b}{4}-1} K_{a-b}\left[\frac{2\sqrt{ab}\sqrt{\gamma}}{\Gamma}\right] d\gamma \qquad (9)$$

and expressing *ln (1+γ)* and $K_v(.)$ as in [11], a closed-form mathematical expression could be derived as shown in the equation (10)

$$< c > = \frac{B\left(\frac{ab}{\sqrt{T}}\right)^{\frac{y1}{2}}}{4\pi T(a)T(b)\ln(2)} \times G_{2,6}^{6,1}\left[\frac{(ab)^2}{16T}\middle| \begin{matrix} -\frac{y1}{4}, & -\frac{y1}{4}+1 \\ \frac{y2}{4}, & \frac{y2+2}{4}, -\frac{y2}{4}, \frac{-y2+2}{4}, -\frac{y1}{4}, -\frac{y1}{4} \end{matrix}\right] \qquad (10)$$

V. CONCLUSION

In this paper certain investigations on atmospheric strength models prediction for FSO application is discussed. Obviously the model provides the basis for making predictions about the outcomes of experiments and/or measurements. The direct methods to practical atmospheric problems are usually given by sheer size and complexity of the atmosphere. Most of the existing models are derived from the data corresponding to their local atmospheric conditions; therefore they failed to attain the generalization on predicting the atmospheric turbulence strength. Furthermore these models do not offer any suitable means to tune their parameters to fit to new test fields. From this, it is concluded that, new models become significant to provide more accurate prediction on atmospheric turbulence strength.

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